Oct. 24, 1967 W. N. LATHAM 3,349,161

ELECTRICAL LEADS FOR CRYOGENIC DEVICES

Filed Dec. 30, 1964 6 Sheets-Sheet 1

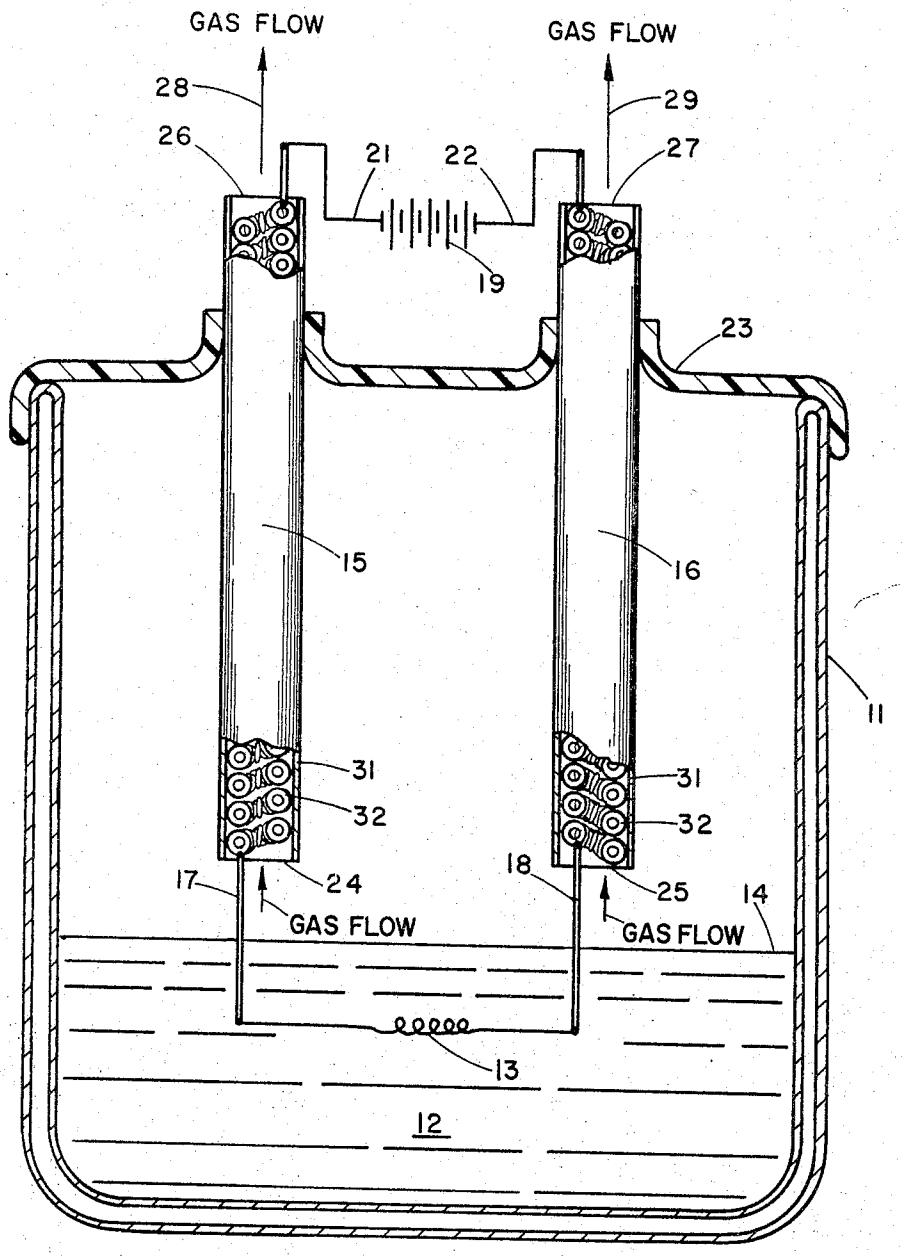


FIG. 1

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ELECTRICAL LEADS FOR CRYOGENIC DEVICES

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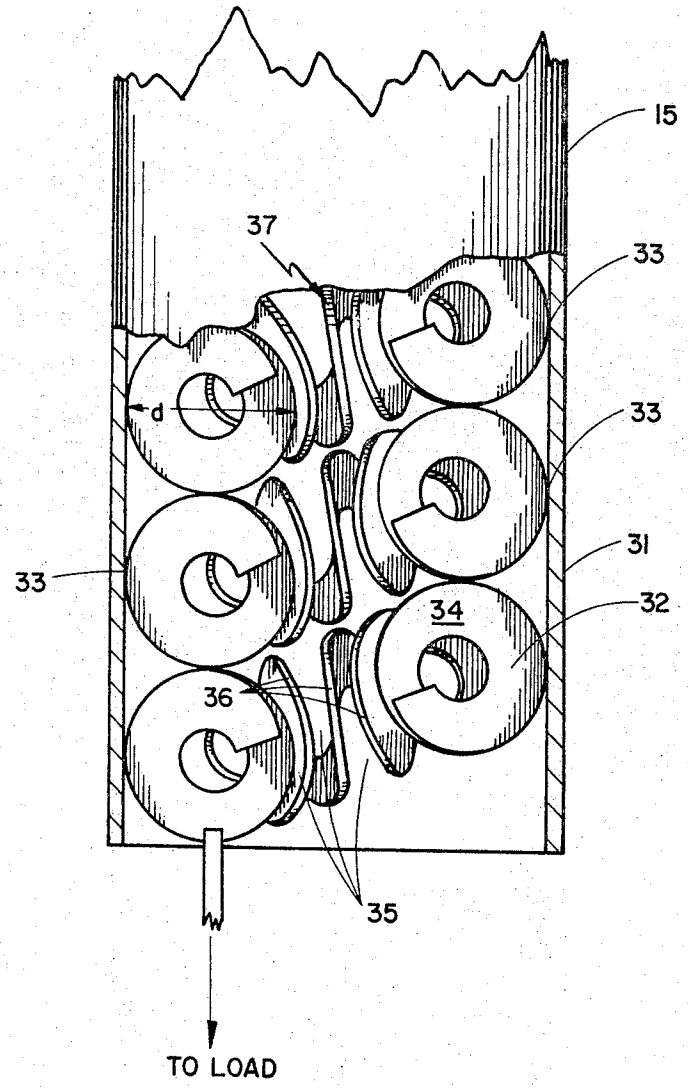


FIG. 2

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ELECTRICAL LEADS FOR CRYOGENIC DEVICES

Filed Dec. 30, 1964 6 Sheets-Sheet 3

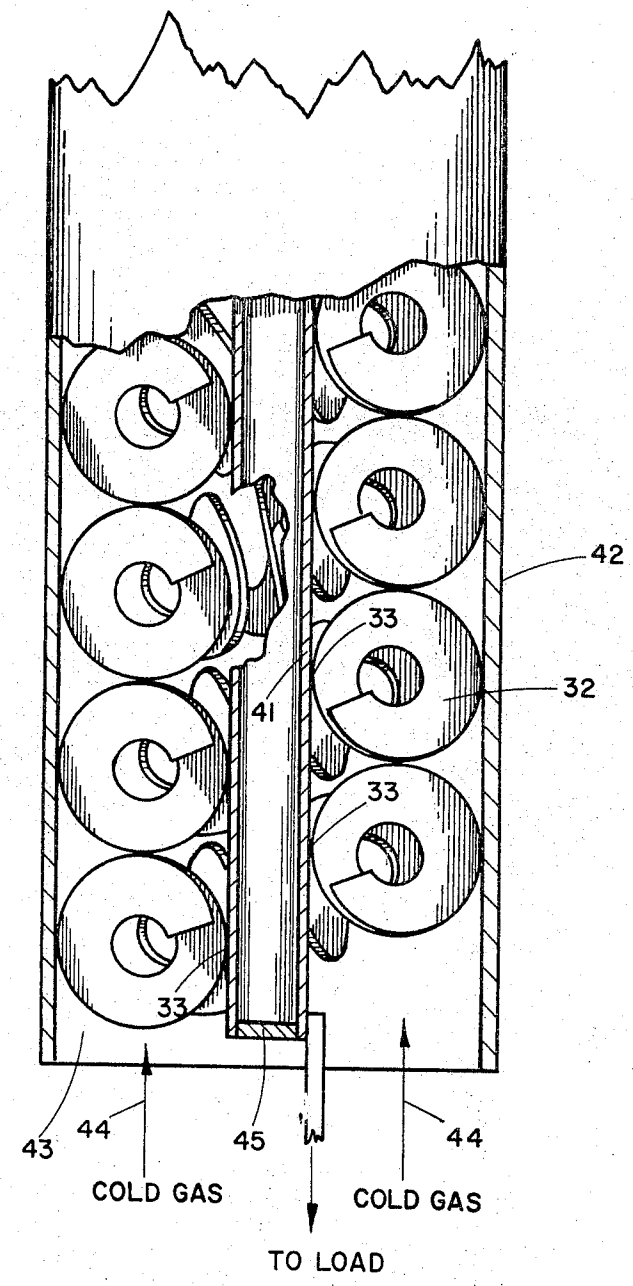


FIG. 3

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ELECTRICAL LEADS FOR CRYOGENIC DEVICES

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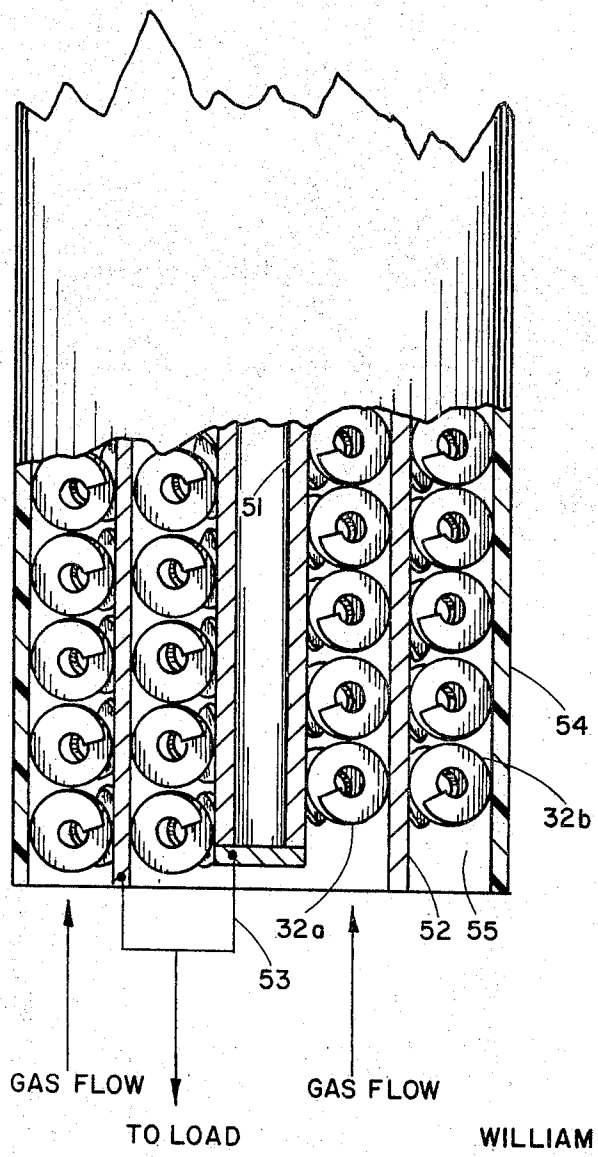


FIG. 4

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ELECTRICAL LEADS FOR CRYOGENIC DEVICES

Filed Dec. 30, 1964 6 Sheets-Sheet 5

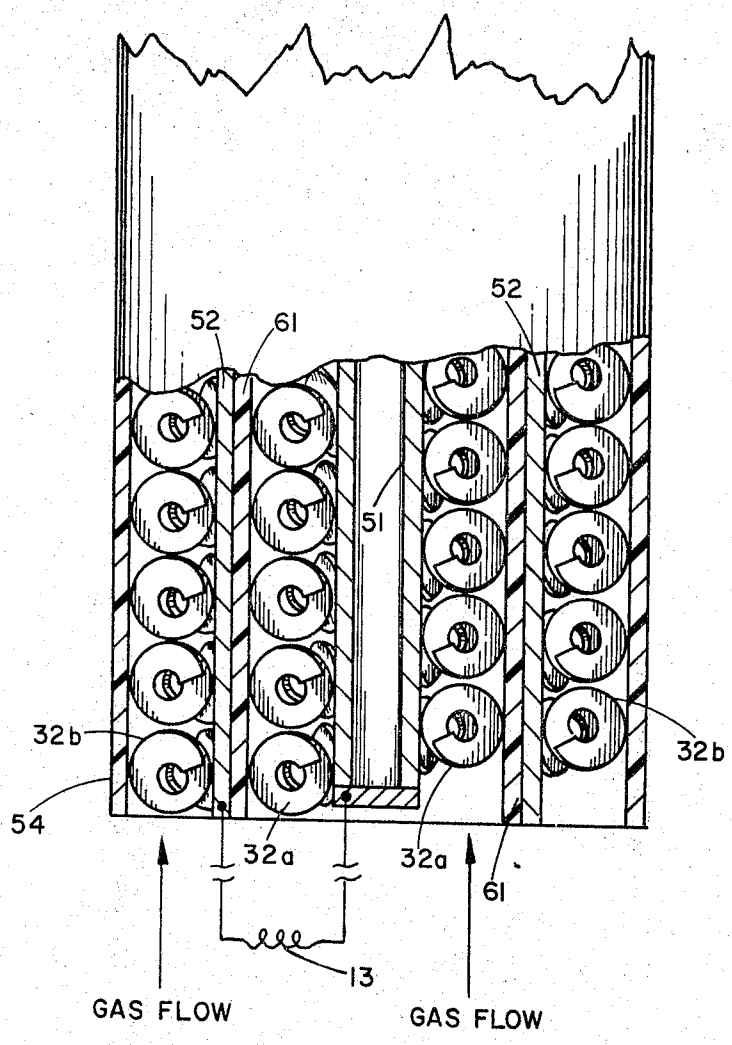


FIG. 5

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ELECTRICAL LEADS FOR CRYOGENIC DEVICES

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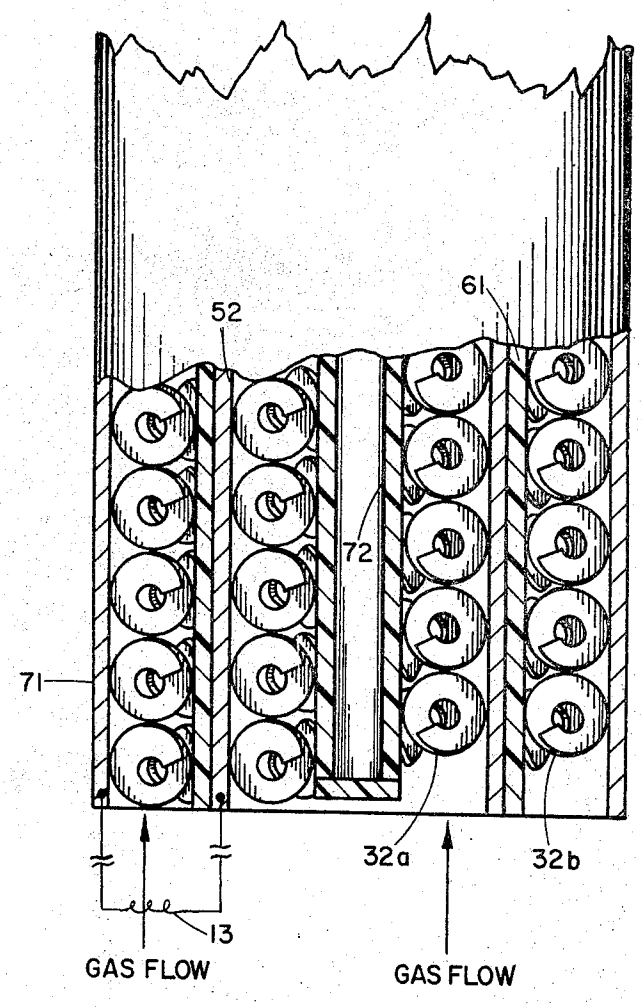


FIG. 6

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United States Patent Office 3,349,161 Patented Oct. 24, 1967

3,349,161

ELECTRICAL LEADS FOR CRYOGENIC DEVICES

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Filed Dec. 30, 1964, Ser. No. 422,139
9 Claims. (Cl. 174—15)

ABSTRACT OF THE DISCLOSURE

An electrical lead for cryogenic devices wherein gas is forced to flow through an annular hollow member which contains heat transfer means. The heat transfer means define a plurality of gas flow passages substantially parallel to the longitudinal axis of the member, these first gas flow passages comprising a plurality of second axial gas flow passages extending substantially the length of the hollow member.

The present invention is directed to electrical leads and more particularly to electrical leads for devices immersed in a cryogenic medium.

The provision of current via electrical current leads between a warm region (as compared to a cryogenic region) and a cryogenic region, such as for example the interior of a Dewar containing liquid helium, results in the introduction of heat into the cryogenic region. The introduction of heat called "heat leak" results from the combined effect of Joule heating in the leads and heat conduction along the leads from a warm region to the cold or cryogenic region. It is of course desirable to reduce this heat leak to a minimum in order that the cost of the refrigeration, which is required to keep the cryogenic region at a constant temperature, is as low as possible.

Where the cryogenic region is comprised of a liquid coolant bath, attempts have been made to reduce the quantity of heat reaching the coolant bath by cooling the electrical leads for the device immersed in the coolant bath with the boil-off gas produced by that heat which does reach the bath. Such cooling of the leads is particularly attractive with helium which has the property that a pound of helium warmed from liquid temperature to room temperature absorbs about eighty times as much heat as the same pound of liquid helium will absorb when evaporated. For a discussion of an exemplary prior art cooled electrical lead, the solution of the equations of steady heat flow in cooled leads, and the design of such leads, reference is made to "Counterflow Current Leads for Cryogenic Applications" by J. E. C. Williams, in Cryogenics, vol. 3, No. 4, December 1963, published by Hewood and Co., Ltd., London and New York.

It is an object of the present invention to provide improved electrical leads for cryogenic devices.

It is another object of the present invention to provide for cryogenic devices electrical leads having as a characteristic more efficient heat exchange by reason of their construction and arrangement.

A further object of the present invention is to provide electrical leads for cryogenic devices which are simple and economical of construction, and which are practical and reliable in operation.

A still further object of the present invention is to provide electrical leads for cryogenic devices which are more compact, lighter in weight, which have a lower gas pressure drop, and which carry higher currents than can be realized with prior art designs.

In achieving the foregoing general objectives, there is provided a hollow member for receiving gas from a cryogenic region and venting it to a warmer region. Electrically-conductive heat transfer means disposed in and

in contact with the hollow member provides a plurality of first gas flow passages substantially parallel to the longitudinal axis of the hollow member which in turn comprise a plurality of second axial gas flow passages extending substantially the effective length of the hollow member. In accordance with an embodiment of the present invention designed to carry 200 amperes, there are provided two spaced and concentric annular members at least one of which is a good electrical conductor, the annular space between the members containing a material in the form of a coil having good thermal conductivity characteristics and high heat transfer area per unit volume of coil helically wound on the inner cylinder and forming a further coil for transferring heat from the electrical conductor to the cold gas from the cryogenic environment which is forced to flow only through the said annular space.

The novel features that are considered characteristic of the invention are set forth in the appended claims; the invention itself, however, both as to its organization and method of operation, together with additional objects and advantages thereof, will best be understood from the following description of a specific embodiment when read in conjunction with the accompanying drawings, in which:

FIGURE 1 is a sectional side view of a Dewar defining a cryogenic region containing electrical leads in accordance with the present invention;

FIGURE 2 is a sectional side view on an enlarged scale of a single tube electrical lead in accordance with the present invention;

FIGURE 3 is a sectional side view of a modification comprising a two-tube electrical lead in accordance with the present invention;

FIGURE 4 is a sectional side view of a further modification for very high current flow;

FIGURE 5 is a sectional side view of a further modification wherein two leads are incorporated in a single structure; and

FIGURE 6 is a sectional side view of a modification of the embodiment shown in FIGURE 5.

Referring to FIGURE 1, there is shown a Dewar **11** containing a cryogenic liquid **12**, such as for example liquid helium. Immersed in the cryogenic liquid **12** is an electrically-conductive load **13** intended to be operated at cryogenic temperatures, i.e., the temperature of, for example, liquid argon, helium, hydrogen, neon, nitrogen, or oxygen. Although shown as a coil the electrically-conductive load **13** may be any kind of device or load requiring a supply of electrical current.

Above the surface **14** of the cryogenic liquid **12** are provided two hollow and elongated electrical leads designated respectively by the numerals **15** and **16** which convey current between a warm region (the region exterior of Dewar **11**) and a cryogenic region (the liquid **12** in the interior of the Dewar **11** for example). The leads **15** and **16** also vent the boil-off gas produced by the heat which does reach the cryogenic liquid **12**, thereby reducing heat leak into the cryogenic region via the electrical leads **15** and **16**.

The electrical leads **15** and **16** are connected to the load **13** via conductors **17** and **18** and to a source of current designated by battery **19** via conductors **21** and **22**.

The open end of the Dewar is sealed by a cover **23** adapted to receive and electrically insulate from each other electrical leads **15** and **16**. The boil-off gas enters the leads at their open ends **24** and **25** adjacent to the cryogenic liquid and leaves the leads at their ends **26** and **27** in the warm region. The warm region incidentally need not be at room temperature but merely at a temperature greater than that of the cryogenic region. For example, the cryogenic region may be at substantially the temper-

ature of liquid helium, whereas the region exterior of the Dewar receiving the boil-off gas may be at substantially the temperature of liquid nitrogen. The boil-off gas leaving each lead designated by the arrows **28** and **29** may be collected in conventional manner and reliquified or may be permitted to escape into the atmosphere. The transfer tube for the cryogenic liquid has been omitted for clarity.

Directing attention now to the electrical leads **15** and **16** which are identical and particularly to FIGURE 2 which shows one of the leads on a greatly enlarged scale, it will be noted that each lead comprises a hollow member **31** which may be either a good or poor electrical conductor. Disposed within each hollow member are heat transfer means **32** comprising a coil providing axial gas flow passages (passages substantially parallel to the longitudinal axis of each member) extending substantially the effective length of each member. Most conveniently, the heat transfer means **32** are formed of a relatively thin and continuous ribbon of flat copper strip first formed into a coil (as best shown in FIGURE 2) and then helically wound about the longitudinal axis of each hollow member **31** to form a second coil, the outer periphery of which is in contact as at points **33** with the hollow member **31**. Where the hollow member **31** is formed of a good electrical conductor, the coiled copper strip or ribbon is preferably soldered to the hollow member to provide maximum heat transfer from the outer member **31** to the cold gas passing through each member. It should be noted that the above-described single-tube construction is suitable for only low current application if the tube or member **31** is not a good electrical conductor. In order to provide maximum heat transfer to the cold gas, the diameter of the center portion **37** of member **31** is made as small as possible. Accordingly, if the diameter *d* of the coil is only slightly less than about one half of the internal diameter of the hollow member, maximum packing of the ribbon in each member and minimum free gas flow up the center portion **37** can be effected.

Since the principal surfaces **34** of the ribbon (those surfaces in the width dimension of each ribbon as best shown in FIGURE 2) are parallel to the longitudinal axis of each member and different portions thereof are spaced apart, they form a plurality of first gas flow passages **35** substantially parallel to the longitudinal axis of each member. These first gas flow passages **35** in turn comprise a plurality of second axial gas flow passages extending substantially the effective length of each member, thus providing low thermal conductance and gas pressure drop in the direction of the longitudinal axis of each member, a high heat transfer coefficient between the electrical lead and the gas flowing therethrough and a high ratio of heat transfer surface to the volume defined by each hollow member. To make a high current lead, each hollow member must be fabricated from a good electrical conductor. In this case, conductors **17**, **18**, **21**, and **22** may be connected to these members rather than to the ribbon as shown in FIGURES 1 and 2.

For the determination of optimum dimensions of the electrical leads in relation to a given current, a given cryogenic liquid, and minimum gas flow, reference is made to the aforementioned article by J. E. C. Williams.

FIGURE 2 shows one of the electrical leads of FIGURE 1 on a greatly enlarged, scale to more clearly show the configuration of coil **32**. As will readily be seen from FIGURE 2, the principal surfaces **34** of consecutive turns **36** of the metal ribbon forms a large number of short gas passages **35** oriented axially in the direction of gas flow and these short gas passages in turn form second axial gas passages extending substantially the length of the hollow member.

FIGURE 3 shows a modification wherein first and second concentric annular members **41** and **42** are spaced one from another to form an annular passage **43** for receiving the boil-off gas designated by arrows **44**, the inner member **41** being closed at one end, such as for example end **45**, to prevent the flow of gas therein in an axial direction. At least one of the annular members, such as for example the inner member **41**, should be a good electrical conductor for a high current lead design. In this arrangement, the heat transfer means **32** comprising the coiled electrically-conductive ribbon is disposed in the annular passage. The ribbon is wound around the inner member **41** and soldered to the electrically-conductive member.

Assuming that the inner member **41** is a good electrical conductor, such as copper, the outer member **42** may also be composed of copper or alternately of stainless steel or a true insulator, such as resin impregnated cloth or paper.

FIGURE 4 shows a further modification for carrying very high currents, such as currents in excess of, for example, 1000 amperes. As shown in FIGURE 4, the second member **52** and the innermost member **51** additionally, if desired, are good electrical conductors which may be connected in parallel by conductor **53**. However, since the heat transfer ribbon **32***a* disposed between the aforementioned members **51** and **52** is soldered thereto, a single electrical connection to the load and the source of current will suffice. The outermost member **54** may be an insulator as shown, a further coil of heat transfer ribbon **32***b* being disposed in the annular passage **55** and soldered to the second member. Such an arrangement provides greater heat transfer area and a greater current-carrying cross section than that shown in FIGURE 2.

FIGURE 5 shows a still further modification wherein two electrical leads are incorporated in a single structure in accordance with the present invention. Inspection of FIGURES 4 and 5 will show that FIGURE 5 is essentially the same as FIGURE 4 except that a continuous insulating sleeve **61** is provided between and electrically insulates member **52** from the inner coil **32***a*. The provision of the insulating sleeve **61** permits member **52** and coil **32***b* to function as one electrical lead and member **51** and coil **32***a* to function as the second electrical lead. Accordingly, as shown in FIGURE 5, the load may be connected between members **51** and **52**. Equal heat transfer areas and current carrying cross sectional areas may be provided by varying the pitch of coils **32***a* and **32***b* and/or the thickness of members **51** and **52**. On the other hand, the use of valves (not shown) to control gas flow in each passage may be used to compensate for differences in heat transfer characteristics.

FIGURE 6 illustrates that considerable variation and arrangement of components is possible to meet varying circumstances. Thus, comparing FIGURES 5 and 6, it will be noted that as compared to FIGURE 5, the outermost member **71** in FIGURE 6 is electrically conductive, the innermost member **72** is an insulator or electrically nonconductive, and that the positions of the insulating sleeve **61** and the second member **52** are reversed.

The various features and advantages of the invention are thought to be clear from the foregoing description. Various other features and advantages not specifically enumerated will undoubtedly occur to those versed in the art, as likewise will many variations and modifications of the preferred embodiment illustrated, all of which may be achieved without departing from the spirit and scope of the invention as defined by the following claims.

What is claimed is:

1. In an electrical lead wherein a cold gas in a cryogenic region passes through said electrical lead to a warmer region, the combination comprising: first and second concentric annular members spaced one from another to form an annular passage for receiving said gas, at least one of said members being a good electrical conductor and said inner member being at least substantially impervious to the flow of gas in the direction of its longitudinal axis; and electrically-conductive heat trans-

fer means disposed in said annular passage and in thermal contact with said electrically-conductive member, said heat transfer means comprising a first coil formed from a flat metal strip and helically wound around the inner member to form a second coil, said strip having two principal surfaces oriented substantially parallel to the direction of gas flow.

2. In an electrical lead wherein a cold gas in a cryogenic region passes through said electrical lead to a warmer region the combination comprising: a first elongated metal cylinder surrounded by and spaced from a second elongated cylinder to form an annular passage for receiving gas from said cryogenic region, said second cylinder being a poor thermal conductor and said inner cylinder being at least substantially impervious to the flow of gas in the direction of its longitudinal axis; and heat transfer means having high thermal conductivity disposed in said annular passage and in thermal contact with said first cylinder, said heat transfer means comprising a first coil formed from a flat metal strip and helically wound around said first cylinder to form a second coil, said strip having two principal surfaces oriented substantially parallel to the direction of gas flow whereby said electrical lead has low thermal conductance and low gas pressure drop in the direction of gas flow, a high heat transfer coefficient between said first cylinder and gas flowing through said annular passage from said cryogenic region and a high ratio of heat transfer surface of said heat transfer means to the volume of said annular passage.

3. In an electrical lead wherein a cold gas in a cryogenic region passes through said electrical lead to a warmer region, the combination comprising: a hollow electrically-conductive member for receiving said gas; electricaly-conductive heat transfer means disposed in and in thermal contact with said member, said heat transfer means having principal surfaces different portions of which define a plurality of first gas flow passages substantially parallel to the longitudinal axis of said electrically-conductive member, said first gas flow passages forming a plurality of second axial gas flow passages extending substantially the effective length of said members whereby said electrical lead has low thermal conductance and gas pressure drop in the direction of said longitudinal axis and a high heat transfer coefficient between said electricaly-conductive member and gas flowing through said annular passage from said cryogenic region; and an inner member at least substantially impervious to the flow of gas whereby said gas flows substantially only through said first and second gas flow passages.

4. The combination as defined in claim 3 wherein said heat transfer means comprises a coil formed from a flat metal strip, said strip being helically wound about the longitudinal axis of said member.

5. In an electrical lead wherein a cold gas in a cryogenic region passes through said electrical lead to a warmer region, the combination comprising: a first inner annular member impervious to the flow of gas in the direction of its longitudinal axis; a second annular member surrounding and spaced from said first member to form a first annular passage, at least one of said first and second members being a good electrical conductor; a third annular member surrounding and spaced from said second member to form a second annular passage; and first and second coils respectively formed from flat metal strip and having two principal surfaces oriented substantially parallel to the longitudinal axis of said first member, said first coil being disposed in said first annular passage and helically wound around said inner member to form a third coil and said second coil being disposed in said second annular passage and helically wound around said second member to form a fourth coil.

6. The combination as defined in claim 5 wherein said first and second coils are electrically coupled one to another.

7. The combination as defined in claim 5 wherein said second member is a good electrical conductor and said first and second coils are in electrical contact with said second member.

8. The combination as defined in claim 5 wherein said first and second coils are electrically insulated one from another.

9. The combination as defined in claim 5 wherein said second member is a good electrical conductor and electrically-nonconductive means covers one surface of said second member whereby said first and second coils are electricaly insulated one from another.

References Cited

UNITED STATES PATENTS

2,680,357	6/1954	Collins	165—141 X
3,286,014	11/1966	Williams	174—18 X

FOREIGN PATENTS

1,263,730	5/1961	France.

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